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SCHOOL OF ENGINEERING
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

Technical Report 75-T11

(NASA-CR-143430) INVESTIGATION OF CURRENT UNIVERSITY RESEARCH CONCERNING ENERGY CONVERSION AND CONSERVATION IN SMALL SINGLE-FAMILY DWELLINGS Final Technical Report, 7 Apr. - 7 Aug. 1975 (Old Dominion

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INVESTIGATION OF CURRENT UNIVERSITY RESEARCH
CONCERNING ENERGY CONVERSION AND CONSERVATION
IN SMALL SINGLE-FAMILY DWELLINGS

By

G.R. Crossman

and

A.S. Roberts, Jr.



Final Technical Report

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
NASA Grant NSG 1172
April 7 - August 7, 1975

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Submitted by the
Old Dominion University Research Foundation
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INVESTIGATION OF CURRENT UNIVERSITY RESEARCH
CONCERNING ENERGY CONVERSION AND CONSERVATION
IN SMALL SINGLE-FAMILY DWELLINGS

BY

G. R. Crossman¹ and A. S. Roberts, Jr.²

SUMMARY

A four-month investigation has been made of present or recently completed university research concerning energy conversion and conservation techniques which may be applied in small single-family residences. Information has been accumulated through published papers, progress reports, telephone conversations, and personal interviews. A synopsis of each pertinent investigation was written and is contained in this report. Finally, a discussion of the synopses is presented and recommendations are made concerning the applicability of concepts for the design and construction of NASA-Langley Research Center's proposed Technology Utilization House in Hampton, Virginia.

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INTRODUCTION

During the past decade but particularly in the last few years, there has been an increasing concern about the reduction of our present energy resources. Worse still is the fact that diminishing supply is met with an increasing energy demand. This concern has caused industry, government agencies, research organizations, and university researchers alike to attack the problem and attempt to develop practical methods to (1) reduce energy consumption, and (2) increase our energy supply by utilizing available alternate resources (sun, wind, etc.). Investigations have become so widespread and diverse that it is becoming increasingly difficult to keep abreast of the latest energy conversion and conservation developments. The purpose of this paper is to present results of a study concerning one important area of these investigations.

The investigation reported herein concerns current university or college research in North America which involves methods for energy conversion and conservation in small single-family dwellings. Of course, all conceivable energy conservation and conversion schemes are not currently practical, hence this report will emphasize those aspects which can be cost-effective to the average consumer who is primarily interested in the cost of comfortably operating his home. Emphasis will also be placed on results which may be applied immediately or within the next five years.

Furthermore, the study is aimed at discovering research and development recently completed or in advanced stages of development. Other objectives included under the primary objective are to (1) synopsise all pertinent incoming information, (2) systematically organize these synopses, (3) assess the data obtained as to applicability for immediate use or use in the next five years, and (4) present recommendations regarding suitability as to performance, cost-effectiveness, and interaction with other systems.

It is hoped that some results of this study may be applied in the design of NASA-Langley's Technology Utilization House.

METHOD OF APPROACH

In order that this report be completed in time for its results to be utilized in the design of NASA-Langley's Technology Utilization House, there was a time limitation of four months (April 7, 1975 to August 7, 1975) for the study. It was imperative that information be gathered as quickly as possible so that proper evaluation and recommendations could be made in the time allotted.

Immediately upon receipt of the grant, the authors drafted a form letter (Appendix A) and, using numerous sources, sent the letter to over one hundred universities and colleges in North America (Appendix B) requesting any information on work they may be doing related to this study. Sources for potential respondents included published papers, lists of those attending related conferences and workshops, Engineering Education, "Engineering College Research and Graduate Study," (March 1975), personal knowledge, referrals by other researchers, and other means. However, only a small percentage of those contacted were actually involved in investigations related to our study and the overall response was approximately 25 percent. In cases when no response was received from a university performing well-known work in the field, either a follow-up letter was sent, or a telephone communication was made. Responses to initial letters were spread over a two and one-half month period. Personal contacts made with several university researchers at the Heat Pump Conference at Pennsylvania State University (June 12-14, 1975), however, subsequently resulted in valuable communications.

From the responses received, either by letter or telephone follow-up, visits were planned to various campuses where investigations are being pursued to observe and discuss with the investigators their respective projects. Financial limitations restricted travel and much consideration was given to deciding which personal visits would be most beneficial to this study. Visits were made to Pennsylvania State University, Princeton University, University of Pennsylvania, University of Delaware, Ohio State University, Massachusetts Institute of Technology, Colorado State University, and the University of Florida.

Using the results of visits and other responses, a synopsis of each applicable investigation was then developed in the following manner: Each synopsis was headed by the general area of the investigation, and this was followed by the particular topic discussed in the synopsis, the principal investigator, university or college affiliation and, finally, the body of the synopsis.

The synopses were then categorized according to general topic (not alphabetically). A synopsis which encompassed more than one general topic is presented once completely under its main topic but is listed under each general topic discussed, and referenced to the complete synopsis. The synopses are located in Appendix C. Appendices D and E, respectively, provide indices of principal investigators and universities and colleges cited in this report.

Finally, after the systematic organization of the synopses, a discussion of their important aspects, including such items as cost-effectiveness, system efficiencies, and energy savings, was summarized. An assessment of immediate applicability or availability within the next five years was made along with recommendations.

DISCUSSION

From the time that input to this study began accumulating it was apparent that, of the investigations being performed at universities and colleges in North America, most were involved with the conversion of solar energy to a more useful form. In fact over 75 percent of the synopses presented in Appendix C are involved with either solar energy collection, storage, or utilization. Other general areas of investigation presented in this report are control of thermal losses (and gains) in housing, off-peak cooling, and control devices for energy conservation. Inquiries were made concerning work at colleges and universities in such areas as residential waste water recycling, fire protection and security systems, and the use of wind power in residences. It appears that investigations in these areas are not presently being pursued, although one well-engineered demonstration house does incorporate smoke detectors

(C-7)* and Professor W.E. Heronemus of the University of Massachusetts has recently been awarded a National Science Foundation contract for "Investigation of the feasibility of using windpower for space heating in colder climates."

As was mentioned in the Method of Approach section, the synopses are categorized according to general topic. The first section of synopses is Thermal Loss/Gain Control and includes such specific topics as insulating techniques, architectural features, landscaping, and thermal loss management. The three following sections all involve solar energy -- Solar Energy Collection, Solar Energy Storage, and Solar Energy Utilization which includes subtopics of Heating; Cooling; and Hot Water, Photovoltaics, and Dehumidification. The last two sections are Off-Peak Cooling and System Control. These sections will be discussed separately.

Thermal Loss/Gain Control

During the course of this study, it was realized that, due to the relatively high cost of collecting and utilizing solar energy in residences, a primary emphasis should be placed on energy conservation in housing (reducing heat losses in winter and heat gains in summer). Vanderbilt University has reported on the relationship between heat loss effects and a solar heating system (C-12).

An important prerequisite to reducing heat losses or gains in housing is to determine their sources. Princeton University is doing significant work in measuring heat losses due to conduction and infiltration (C-3). Better insulation is a well-known method for reducing losses and studies are being performed to optimize insulation thicknesses (C-11). Most new experimental houses are using styrofoam as total or supplemental insulation (C-6, C-32). Although cost-effectiveness has not yet been published, investigations at Ohio State University (C-5) have indicated good relative effectiveness for styrofoam. Other than the readily accepted methods of

* The letter and number in parentheses refers to Appendix and page number respectively, in this paper.

reducing heat flow through windows (double-glazing, storm windows), work is being done in the development of thin films to absorb solar energy during the winter while reflecting it during the summer (C-9). An obvious method for reducing window heat fluxes is to minimize window area. This has been done in new "solar" experimental houses at Ohio State University and Tennessee Technological University (C-32, C-6). In fact, the Ohio State Solar Home has practically no windows, but uses four atria with tops of double-glazed reflective glass.

There are numerous architectural features being tried in newly designed and recently built "demonstration" houses (C-6, C-7, C-10, C-13, C-32). Although experimental data is not available as to their effectiveness in energy loss reduction, some features such as proper roof overhang for summer shading and winter sun will unquestionably reduce unwanted heat transfer. Other unique architectural features being utilized are "air locks" at entrances, closet and storage space location on outside walls whenever possible for natural insulation, and fans for attic ventilation.

Proper landscaping, although often neglected, is very important in reducing energy losses in a residence. As has been shown by tests at Princeton University (C-8), proper placement of trees, shrubs, and fencing can reduce infiltration as well as convection heat losses. Trees can also provide shading in summer.

Solar Energy Collection

Solar collectors are an integral part of any solar energy utilization system. There are several collector configurations available and comparisons of the relative efficiencies and cost-effectiveness of liquid medium collectors have been made analytically (C-18, C-40) and experimentally. Probably the most extensive recently completed experimental evaluation was made at the University of Pennsylvania (C-15). Both investigations favor the use of single glazed, 3/8-inch-thick air space, with a black "Roll-bond" absorber in temperate climates. Double-glazed is

preferred for colder regions of the country. In the tests at Pennsylvania (C-15) "selective" black coatings also appeared to be cost effective. The use of glazing films (MgF_2) also increases the collector efficiency (C-18). New types of collectors are being investigated (C-19) which produce higher efficiencies but have not yet proven to be more cost-effective.

Collectors with air as the medium have been used successfully at Colorado State University and the University of Delaware (C-34), and are generally simpler in design. Integration with a storage system is then more complicated since a different storage medium must be used. Air systems appear to be more easily integrated with photovoltaic cells, such as those being investigated at Delaware (C-34, C-54). A unique collector being used at the University of Nebraska (C-36) uses a south-facing transparent roof at no additional cost to collect solar energy by heating the attic air which is then transported to spaces. More investigations of simple inexpensive designs such as this are needed. Investigations into the corrosion of collector absorbers and possible inhibitors is being performed at Dartmouth College (C-38).

Solar Energy Storage

There are two methods presently used for the storage of solar energy--sensible heat storage and latent heat-of-fusion storage. Sensible heat storage most generally is in water tanks or, in cases where air is used as the collector medium, in rocks. Due to the relatively large volumes (or weights) required for sensible heat storage, several investigations have focused on latent heat-of-fusion materials (approximately one-eighth the volume of water storage) (C-24, C-25, C-26). These materials also have the ability to supply heat at a constant temperature, an important consideration in heat pump performance. Continuing studies at the University of Delaware (C-24) indicate that some salt hydrates and their eutectics may be commercially available in the near future. Studies are also continuing at North Carolina State University (C-26) and Ohio State University (C-32) in the use of paraffin waxes as latent heat storage media.

Research is being performed at Michigan State University (C-27) concerning the use of ground water aquifer for solar energy storage, but it is doubtful that application for residential use will occur in the next five years.

An analytical study into the possibility of large amounts of energy in the absorption cycle was made at the University of California-Davis (C-28). The study indicated feasibility of the system but, unless other refrigerant-absorbent pairs are discovered, use of this storage technique is not promising.

Solar Energy Utilization

Heating. Primarily, two methods for space heating in a home have been studied: direct solar heating via a heat exchanger, and indirect solar heating using a heat pump and at least two heat exchangers. Direct solar heating using a hydronic system and, alternatively, a forced air system is being studied at the University of Florida research house (C-37). Ohio State University and the University of Delaware use modal operation of the direct and indirect systems in their test facilities, and are in the process of evaluating their relative performance (C-32, C-34). Performance data are not yet available in these studies although it is generally felt that when sufficient collector or storage temperatures can be maintained, that direct heating is more cost-effective. Optimization studies (C-40) and computer modeling (C-39) should be able to indicate whether this is true. An analytical comparison conducted at the University of Pennsylvania (C-42) indicated that direct solar heating was more cost-effective.

Some heat pump performance data is available from the Ohio State University and Dartmouth College residences (C-32, C-38) which indicate maximum COP's (coefficients of performance) of 3.0 (although at different evaporator conditions). Solar augmented heat pumps are being installed in newly designed test homes of Tennessee Technological University (C-6) and the University of Nebraska (C-36). The heat pump at the Nebraska facility will use solar heated attic air and it is estimated that the annual heating/cooling bill will be approximately \$75.

A comparison study of conventional heating methods at the University of Oklahoma (C-41) indicated better energy utilization by the heat pump than other means, with the added advantage of being able to utilize solar energy. A report by Ohio University (C-43) indicates that for colder climates complete heating by solar heat pumps is not feasible, and some auxiliary heating will be required.

Cooling. There are several methods by which solar energy may be utilized for effective cooling but due to excessive costs and construction restrictions (C-45) only one is being investigated to any degree--absorption cycle cooling. At least three universities have solar assisted absorption systems installed and operating in demonstration homes. Colorado State University (C-46) and Ohio State University (C-32) both have 3-ton Arkla-Servel lithium-bromide units installed, and the University of Florida (C-45) is using a component-constructed intermittent ammonia-water system. In addition, intermittent ammonia-water and ammonia-sodium thiocyanate systems are being studied at the University of Western Ontario (C-47). Although complete performance data is not yet available on all three residence-installed units, COP's on the order of 0.3 have been attained, which is relatively low. Optimization studies at the University of Maryland indicate maximum attainable COP's of about 0.8 (C-48). These optimization studies include selection of proper collectors.

A major consideration in the use of absorption cooling systems is the high temperature (not less than 170°F) needed in the generator. Collection of solar energy at this temperature by the flat collectors is less efficient than low temperature collection and there is an additional problem of extra insulation for storage tanks.

Although 3-ton absorption units are available commercially from Arkla-Servel at costs on the order of \$3000, additional costs involved in solar collection and storage prevent it from being cost-effective at this time. It is important that these systems be developed further, or alternate solar cooling systems found if year-round utilization of solar collectors is to be realized.

The effectiveness of using solar collectors as night-time radiators is to be studied at Dartmouth College during the summer of 1975 (C-38).

Hot Water, Photovoltaics, and Dehumidification. Solar-supplemented hot water heating systems are being used in most of the university demonstration homes but separate analyses of their performance is not available. The University of Connecticut has proposed a study (C-53) of the cost-effectiveness of adding a solar hot water preheating system to an existing residential system. The system contains drainable collectors (to prevent freezing) which heat the incoming water directly. This direct heating is a major deviation from most solar hot water heating systems which use heat exchangers.

Thus far discussion has primarily involved the conversion of solar energy to one form, heat. Another form of energy which is readily used in the home is electricity. There is research being conducted on the conversion of solar energy to direct current electricity through the use of photovoltaic cells. These cells have been mainly used in aerospace applications but more recently investigations have been directed towards terrestrial application. The University of Delaware has installed cadmium-sulfide cells on the absorbers of collector plates and they are investigating all aspects of utilizing the electricity produced (C-54). At Arizona State University silicon solar cells are being studied coupled with fuel cell storage (C-55). A solar-powered residential electric system is presently being studied at the University of Florida (C-37). It appears at this time that the high manufacturing costs of solar cells prevents residential application, although Delaware is researching methods to reduce this cost. Solar cells are commercially available, but current costs are of the order of \$1000 to \$2000/m² for silicon cells.

It appears that solar dehumidification in residences is not feasible at this time although a large solar-operated wet desiccant dehumidifier is being put into operation in a large office building by the Massachusetts Institute of Technology (C-57).

Off-Peak Cooling

Off-Peak Cooling generally involves the use of a heat pump running reversibly at night to remove heat from a "cold" storage tank to which heat has been added during the day from the spaces via a heat exchanger. This mode of operation has two advantages: (1) higher COP values for the heat pump due to cooler outside temperatures, and (2) lower peak demand from the utility. Analytical and actual performance studies of this type of operation have been made at the University of Pennsylvania (C-58) with some modification. They used half-capacity compressors running twenty-four hours per day. In two systems tested, one used 10 percent more energy than a conventional system and the other 6 percent less, but both did reduce peak power demand. Unless a break from utilities is obtained for lower peak power demand, it appears from published results that off-peak cooling of this type is not cost-effective. Other systems, such as those installed in the test residences at the University of Delaware (C-34) and the University of Nebraska (C-36), need to be tested and evaluated.

System Control

In order to achieve maximum energy savings a heating/cooling system should have adequate system controls. Two important types are zone controls for efficient heating and cooling of occupied areas, and mode controls for proper selection of the most efficient mode for heating or cooling (direct solar heating, heating from storage, auxiliary heating, etc.). Solid state zone controls are being developed at Princeton University (C-3) while the University of Delaware is abandoning its pneumatic controls and installing electronic equipment for mode control (C-34). Cost estimates were not available.

If heat pumps are to be used in the solar residence then their operation must be improved. Work is being done at Ohio State University (C-32) and Massachusetts Institute of Technology (C-60) to develop better heat pump control. At MIT a promising variable capacity device has been developed and is being tested. This device can improve the COP's of heat pumps at the higher temperatures which result from collecting solar energy.

RECOMMENDATIONS

A major reason for initiating this study at this time was so that any applicable knowledge gained could be utilized in the design and construction of NASA-Langley's Technology Utilization House. The recommendations contained in this report are based on the results of this study and include considerations of cost-effectiveness and commercial availability. One of the least expensive methods which can be used to conserve energy is to include energy saving features in the architectural design of the house. Simple modifications to existing plans for model houses can reduce heat losses. Such items as proper roof overhang to provide summer shading and winter sun, storm windows, location of closets and storage spaces on outside walls, attic ventilation, and air lock entrances are cost-effective items. Additional insulation can be cost effective when based on engineering design criteria. It is important to optimize heat loss coefficients with respect to initial cost and energy savings over the lifetime of the structure. It appears that the use of commercially available 1-inch styrofoam over fiberglass batts may be cost-effective.

Proper orientation of the house is important, as well as landscaping, placement of trees, shrubs, and fences. These can be very aesthetic while being cost-effective in reducing air infiltration and convection losses from outside walls.

It appears that for solar collection the most cost-effective collector for heating application for southeastern Virginia is the single-glazed with flat black absorber coating using a liquid medium. Water storage is recommended since as yet the heat-of-fusion materials are not fully developed or commercially available and rock storage in basements is not practical for this area. There is the possibility that heat-of-fusion materials may be attractive within the next five years. It is felt that a solar augmented heat pump with alternate direct solar heating is the most suitable energy conservation technique for heating, although its overall cost-effectiveness is questionable. A detailed economic

analysis factoring in local constraints is required. A payback period of not more than twenty years is a conservative criterion to apply to amortization of the incremental capital outlay for solar/heat pump equipment versus conventional heating equipment. (The authors are not convinced that direct solar heating, because of the higher collector temperature involved, is more efficient than solar augmenting the heat pump. The Langley Research house should be used to do some testing in this area.) It is imperative that computer modeling and optimization techniques be utilized to assure proper sizing of all components--collector, storage, heat pump--and to account for local weather conditions.

It is not recommended to use any solar operated cooling systems at this time as it is doubtful that absorption cooling can be made truly cost-effective in the next five years. Off-peak cooling systems on which performance has been published have not proven cost-effective but, with the addition of another storage tank (for "cold" storage), the idea does appear feasible.

Proper system control is important and newly developed control methods mentioned in this report should be closely followed. Except for demonstration purposes the use of photovoltaic cells is not recommended, and unless a manufacturing breakthrough is made they will not be cost-effective for residential use in the near future.

APPENDIX A



School of Engineering • 804-489-6321 • P. O. Box 6173 • Norfolk, Va. 23508

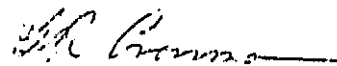
April 10, 1975

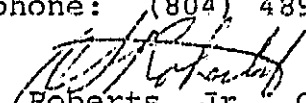
Dear University Researcher:

We recently initiated an information gathering project, due for completion by the end of July, under a grant from NASA Langley Research Center, to determine active applied research at universities involving energy conversion and conservation techniques for single-family dwellings. NASA will soon build an experimental house, and we have the task of assembling information on energy-saving devices and concepts being investigated in the colleges and universities which may be commercially available within five years. Architectural and engineering innovations are being catalogued.

If you, your department or institute are engaged in energy conservation or conversion work relating to individual dwellings, please let us know. We would like pre-prints, informal progress reports, and/or any data which gives a clear view of your projects. Appropriate project information will be summarized and cross-indexed in bibliographic form; and, all contributors of useful information will receive a copy of our final report compiling the on-going work in an important energy conservation area - energy efficient single-family dwellings.

Due to the short-term nature of this grant, we would appreciate your response as quickly as possible.


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APPENDIX B

APPENDIX B

LISTING OF COLLEGES AND UNIVERSITIES CONTACTED

| | |
|-------------------------------------|-------------------------------------|
| Alabama, U. of | New Mexico, The U. of |
| Alabama in Huntsville, U. of | New York Inst. of Tech. |
| Arizona State U. | New York at Scotia, State U. of |
| Boston U. | New York at Syracuse, State U. of |
| Brigham Young U. | No. Carolina Agri. & Tech. State U. |
| California Inst. of Tech. | No. Carolina State U. at Raleigh |
| California Poly. State U. | No. Carolina at Chapel Hill, U. of |
| California State U., Fullerton | No. Dakota State U. |
| California, Berkeley, U. of | Notre Dame, U. of |
| California, Davis, U. of | Ohio, State U., The |
| California, Los Angeles, U. of | Ohio U. |
| California, Santa Barbara, U. of | Oklahoma State U. |
| Carnegie-Mellon U. | Oklahoma, The U. of |
| Catholic U. of America, The | Oregon State U. |
| Cincinnati, U. | Pennsylvania State U. |
| Clarkson Coll. of Tech. | Pennsylvania, U. of |
| Colorado State U., The | Pittsburgh, U. of |
| Colorado, The U. of | Princeton U. |
| Connecticut, The U. of | Puerto Rico-Mayaguez, U. of |
| Dartmouth College | Purdue U. |
| Dayton, U. of | Rensselaer Poly. Inst. |
| Delaware, U. of | Rochester Inst. of Tech. |
| Drexel U. | Rutgers U. |
| Florida Technological U. | South Florida, U. of |
| Florida, U. of | Southern Illinois U. at Carbondale |
| George Washington U., The | Southern Methodist U. |
| Georgia Inst. of Tech. | Stanford U. |
| Illinois at Chicago Circle, U. of | Stevens Inst. of Tech. |
| Illinois at Urbana-Champaign, U. of | Tennessee Technological U. |
| Iowa State U. | Tennessee, The U. of |
| Kansas State U. | Texas A & M U. |
| Kansas, The U. of | Texas Tech. U. |
| Kay U. | Texas at Arlington, The U. of |
| Laurentian U. | Texas at Austin, The U. of |
| Lehigh U. | Toledo, The U. of |
| McGill U. | Tulane U. |
| McMaster U. | Tulsa U. |
| Manhattan Coll. | Utah State U. |
| Marquette U. | Vanderbilt U. |
| Maryland-College Park, U. of | Villanova U. |
| Massachusetts Inst. of Tech. | Virginia Poly. Inst. & State U. |
| Massachusetts, Amherst, U. of | Virginia, U. of |
| Memphis State U. | Wake Forest U. |
| Miami, U. of | Washington State U. |
| Michigan State U. | Washington Tech. Inst. |
| Michigan, The U. of | Wayne State U. |
| Milwaukee, School of Engrn. | Western Ontario, The U. of |
| Minnesota, U. of | Wichita State U. |
| Missouri-Columbia, U. of | William and Mary, Coll. of |
| Missouri-Rolla, U. of | Wisconsin-Madison, U. of |
| New Jersey Inst. of Tech. | Yale U. |
| New Mexico State U. | |

APPENDIX C

APPENDIX C

INDEX OF SYNOPSES

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THERMAL LOSS/GAIN CONTROL

Topic: Energy Conservation in Housing, Retrofitting Techniques

Source: Socolow, Robert H., et. al., "Energy Conservation in Housing: Work in Progress and Plans for 1975-76", Center for Environmental Studies - Report No. 19, Princeton University, (April, 1975); personal interview with Dr. Socolow and Mr. David Harrje (July, 1975)

Affiliation: Princeton University, Princeton, New Jersey

Synopsis: This 56 page report on research sponsored by NSF/RANN Grant No. SIA72-03516-A02 explains the present status of the project with reflections on past work (3 years) and a presentation of proposed activities for the next year. From the abstract, "The experimentation and analysis of energy conservation opportunities in residential housing underway at Princeton University is described. The community of Twin Rivers, New Jersey is the research laboratory. The experimental capability, which already includes sixteen lightly instrumented, owner occupied town-houses, three highly instrumented, owner occupied town houses, and one town house rented by the research group -- all identical in floor plan and appliance package --, is being expanded and data are reduced using a wide variety of techniques of engineering statistics and psychology. The principal goals of the research are: (1) improving the state-of-the-art of single-home modeling by field validated analysis, (2) identifying the significant behavioral and structural components of the observed variations in gas and electric consumption, (3) documenting, by means of well designed experiments, the energy savings associated with low-cost residential retrofits, and (4) verifying the effects of commitment and feedback on the residents ability to achieve reduced energy consumption."

Of particular interest to this grant, mentioned in the report are: (1) Use of infrared spectrophotometry for measurement of location of heat losses and gains, (2) Use of an SF₆-tracer device developed jointly by the Bureau of Standards and Princeton University to measure air infiltration rates, (3) The extensive instrumentation being employed and investigated to give remote and more direct readouts, (4) A subtask to streamline NBSLD and other current computer models for use in residential dwellings using experimental data obtained. (Utilities and furnace suppliers calculations based on ASHRAE handbook are too crude, + 30%, and present computer modeling too deterministic), (5) Subtask to develop mean load

profiles for daily energy consumption, needed as inputs into studies of new residential energy sources (fuel cells, solar energy) and of load leveling strategies, (6) Possible methods of retrofitting that are important to note in new buildings: Double attic insulation (9 inches); sealing of duct passage to attic; adequate window caulking, sealing; storm windows and doors with advanced-design sealing frames; sizing of furnace for more continuous operation; zone control with thermostatically activated dampers; adequate duct insulation everywhere; outside ventilation of range in summer. The report also describes tasks comparing behavioral and structural influence on energy consumption.

A personal interview with Dr. Socolow and Dr. David Harrje verified those points mentioned in the report. In addition, they have found an approximately 50% loss of heat flow in an uninsulated duct from the furnace to the duct outlets in the row houses they are investigating. Of extreme importance is proper duct insulation and sealing. During the interview the importance of proper integration of heating and cooling systems into the architectural design of a house was discussed. Thought should be given to the location of duct outlets and returns and location of heater for smallest, shortest duct work with fewest bends to reduce convective/conductive and infiltration losses. They have found largest heat losses in duct tunnels from basement to attic, in corners of outside walls, and other well-known places (around windows, doors, etc.)

They are presently developing a solid state zone control system with electronically activated dampers, with a prime objective being to reduce operating energy to as low a value as possible.

An interesting suggestion they made was to build a house "inside out". In other words, have the masonry on the inside and the insulation on the outside. This allows for heat and cold storage in the masonry. When a change in climate occurs (hot to cold or vice versa), the masonry has stored sensible heat which can provide some of the initially required heat load. They are also in the process of doing performance tests on heat pumps, with no results thus far.

Mr. Harrje suggested two individuals who are building homes with special insulating and conservation techniques.

They are:

- (1) Bob Romanchek, Project Engr., Penn. Power & Light Co., Allentown, Pennsylvania
- (2) Bob Schmidtt, Bob Schmidtt Custom Houses, Cleveland, Ohio.

THERMAL LOSS/GAIN CONTROL

Topic: Comparison of Various Degrees of Insulation

Source: Godfrey, C., (Mr. Godfrey is a Ph.D. candidate under the supervision of Dr. C. F. Sepsy, Asst. Professor) Personal Interview (July, 1975)

Affiliation: Ohio State University, Department of Mechanical Engineering, Columbus, Ohio, 43210

Synopsis: Mr. Godfrey discussed work Ohio State is doing for Dow Chemical Company (Amspec Division) concerning the effects of various degrees of insulation on heating losses from residential homes. The laboratory consists of four houses of similar design having the same geographical orientation. The houses are of frame construction (pre-fab), two story, with a basement and attached garage. The aluminum-sided houses are unoccupied and have different degrees of insulation: (1) Conventional 3½ inch fiberglass between studs with fiberboard sheathing, (2) Fiberglass with ½ inch of styrofoam on outside in place of fiberboard, (3) Fiberglass with 1 inch of styrofoam, and (4) No fiberglass, just 1 inch of styrofoam. In all houses the basement is insulated with ¾ inch styrofoam on inside basement walls and beneath the slab. The attic had approximately 6 inches of fiberglass.

Although no published results are available, results indicate a definite insulating effect improvement by adding styrofoam to the fiberglass. The styrofoam alone insulated a little better than the fiberglass alone. One primary reason for the improvement is, of course, that the styrofoam also covers all stud area (about 30% of outside faces). No accurate data was available on amounts of energy loss reduction since the house had no occupants or appliances in use. It is merely a comparative study. Mr. Godfrey suggested that Mr. V. V. Vercoe, Jr.*, Residential Technical Manager of Amspec may be able to give some cost-effectiveness estimates.

Other work being done under the direction of Dr. Sepsy includes: (1) The study of the effects of occupancy on energy consumption under the Electrical Power Research Institute, and (2) The comparison of energy consumption using heat pumps vs. gas furnaces vs. electric resistance heating. No results of these projects were available at this time.

*V. V. Vercoe, Jr., Amspec, Inc., 1880 MacKenzie Drive, Columbus, Ohio, 43220 (614-457-2580).

THERMAL LOSS/GAIN CONTROL

Topic: Solar Test House Design

Source: Sissom, L. E. and Griggs, E. I., "Stage I Design of a Demonstration/Research Solar House" sponsored by the Tennessee Energy Office.

Affiliation: Tennessee Technological University, Department of Mechanical Engineering, Cookeville, Tennessee.

Synopsis: This paper discusses the preliminary design of a 1912 ft² (+608 ft² garage and 1664 ft² basement) 3 bedroom house, incorporating solar augmented interior heating, hot water heating and absorption cooling systems, to be built in Cookeville, Tennessee. The house will incorporate several energy conserving ideas: (1) "Air locks" at entrances, (2) Double pane windows, minimal glass area, (3) Closet and storage spaces on outside walls for natural insulation, (4) Zone heating and cooling control, (5) Proper roof overhang to utilize winter sun and summer shading, (6) Mansard-parapet roof to hide collectors with 5-ply tar roof to use 6" layer of water for heating/cooling optimization, (7) Double insulated outside walls, R-11 and 1" of styrofoam and redwood siding, (8) 4-mil polyethelene film inside behind paneling to reduce infiltration.

Preliminary cooling loads were obtained from ASHRAE Handbook. Final calculation will utilize NBSLD and computer program for transient performance from University of Wisconsin, using Nashville hourly weather data. It appears that collector area should be approximately 760 ft².

Preliminary design includes separate hot and cold thermal storage. There was nothing in the report concerning specifics on heating, cooling and storage systems. Plans for the house were included in their report.

THERMAL LOSS/GAIN CONTROL

Topic: Fully Engineered Residences

Source: Kiesling, E.W., Letter with brochure entitled
"Engineered Housing," Texas Tech University

Affiliation: Texas Tech University, College of Engineering,
Lubbock, Texas

Synopsis: In his letter, Dr. Kiesling expressed his feeling that demonstration houses be constructed not only for energy conservation but also for function, hazard protection and minimum life cycle costs, using all aspects of design - architectural, structural, mechanical, landscaping, and decorating. .

The brochure briefly describes a demonstration house recently constructed in Lubbock. For occupant protection, it has an inresidence shelter and smoke detectors. For conserving energy, it incorporates such things as double pane, sealed windows, high efficiency air conditioners, forced attic ventilation, solar assisted water heating, a recirculating fireplace, landscaping for shade and insulation, light colored exterior walls, convertible skylights, and flourescent lights. For minimum life cycle costs it has a low profile, flat roof, small overhangs, blow out panels, a wind resistant fence and landscaping for wind protection and low maintenance. For health and comfort, electronic air filters, humidifiers and a water softener are installed.

Although no publications have been prepared, Dr. Kiesling would be eager to discuss the features of the house.

THERMAL LOSS/GAIN CONTROL

Topic: The Use of Trees, Shrubs, Fencing, and Landscaping to Reduce Energy Losses in Housing

Source: Mattingly, G., and E. F. Peters "Wind and Trees - Air Infiltration Effects on Energy and Housing", Center for Environmental Studies. Report No. 20, Princeton University (May, 1975) Personal Interview (June, 1975).

Affiliation: Princeton University, Department of Aerospace and Mechanical Sciences, Princeton University.

Synopsis: In this paper is discussed wind tunnel experimental results on the effect of adding trees, hedges and small fences upwind of a house to reduce heat losses by infiltration by smoothing out the outside pressure distribution on the house. The models tested were identical to a series of townhouses located in Twin Rivers, New Jersey. Generally, infiltration is increased by wind since the windward side of the house experiences a pressure higher than the ambient static pressure (stagnation region) and the leeward side a pressure lower than ambient (wake region). Thus, an uneven pressure distribution on the house exists outside, and air enters the house on the windward side while inside comfort air is drawn out on the leeward side.

Wind tunnel experiments indicated that infiltration was, of course, dependent on wind velocity, but also on the relative direction in which it impinged on the home. When the wind attacked a corner of a house the infiltration rate was approximately 60% higher than if the wind hit a face.

Experiments indicated that a five-foot solid fence upwind of the two-story townhouses reduced infiltration on the order of 30%. The paper suggests that small trees or hedges instead of fences may reduce it even further. Experiments also indicated that tall evergreen trees (about the height of the house) planted one and one-half to two and one-half house heights upwind of the house could reduce infiltration by as much as 60%.

In a personal interview with Mr. Mattingly he discussed results of tests on the actual houses and indicated that the wind tunnel tests were reasonably accurate. A report on these tests is forthcoming.

It is important to note that infiltration depends on many other factors, one, of course, being the tightness of the house. Thus, the percentages quoted above will depend on the relative tightness of a house.

THERMAL LOSS/GAIN CONTROL

Topic: Window Systems

Source: Berman, S.M. (co-author), "Energy Conservation and Window Systems," from a report of the American Physical Society, "Technical Aspects of Efficient Energy Utilization," Summer, 1974, sponsored by NSF/FEA/EPRI.

Affiliation: Stanford University, Stanford, California 94305

Synopsis: This section of the report presents a general and quantitative assessment of the technological factors controlling heat loss and gain through windows. Besides a thorough discussion of window design, orientation, multiple glazing, etc., newer concepts such as cheap, coated plastic films are considered to enhance entrapment of infrared radiation in the winter. The main point made is that after relative window area decisions are made and infiltration problems are solved designers should carefully take advantage of free winter heating and turn away undesirable summer radiation. Apparently, these goals are achievable with cost-effective, current technology.

THERMAL LOSS/GAIN CONTROL

Topic: Architectural Considerations in Solar House Design

Source: Lorriman, D., "The Design of a Solar Home," Proceedings of the Seminar on Solar Heating and Cooling of Buildings, London, Ontario (October, 1974)
(Provided by Dr. R.K. Swartman, University of Western Ontario)

Affiliation: The University of Waterloo, Graduate in Architecture, Waterloo, Ontario, Canada

Synopsis: This paper discussed the design of a solar heated house for southern Ontario. Interesting design features include the following: (1) Room orientation so that the best use of incident solar radiation is made; (2) Auxiliary spaces (closets, stairs, and halls) located at the north end of house where feasible; (3) Location of bathrooms internally since they generally need to be the warmest; and (4) Use of massive block walls to help store some heat and stabilize indoor temperatures.

THERMAL LOSS/GAIN CONTROL

Topic: Effect of Heat Loss on Solar Heating Systems

Source: Nash, R.T., and J.W. Williamson, "The Effect of Heat Loss on Solar Heating Systems," Vanderbilt University (Spring, 1975)

Affiliation: Vanderbilt University, Nashville, Tennessee

Synopsis: This paper initially discusses the four dominant factors - structural heat loss coefficient, solar collector area, solar flux, and external temperature - that determine the solar energy gained and the energy lost from a building. A pictorial relationship between the four factors is presented. The report also includes discussion of the economic factors contributing to the total cost of heating a dwelling over its life; a method for identifying economically desirable combinations of solar energy gain, structural energy loss and thermal energy storage; and, using residential heating requirements throughout the U.S., a determination of a range of acceptable values of structural energy loss which must be achieved if solar heating systems are to be accepted. It is stated that the use of minimum HUD insulation standards is quite inappropriate throughout most of the U.S. if the design of a solar heated home is being considered. In most sections of the country, only a portion of the heating requirement can be met by solar energy, even using the best current building techniques. The best contemporary practice allows heat loss coefficients in the range of 400 to 500 BTU/hr^{°F}, while coefficients of 150 to 350 are required for the solar energy gain to match the structural loss.

The paper mentions that considerable evidence exists showing that it is incrementally cheaper to decrease structural energy loss than to increase solar energy gain, realizing that limits for both exist.

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THERMAL LOSS/GAIN CONTROL

Topic: Insulation Standards for Vermont Residences

Source: Heim, W.P., (Mr. Heim was a student under the guidance of Prof. A.O. Converse) "Insulation Standards for Vermont Residences," Report No. DVE-7 Technology and Public Policy Program, Thayer School of Engineering, Dartmouth College, (January, 1975)

Affiliation: Dartmouth College, Thayer School of Engineering, Hanover, New Hampshire

Synopsis: In this report is presented residential insulation standards for the State of Vermont using optimum insulation amounts based on long term inflated energy prices and late 1974 construction prices. The degree-day method is used to determine the heat transfer coefficients listed in the standards. The standards meet those proposed by NBS and ASHRAE, being even more restrictive. The amounts of proper insulation are based on cost-effectiveness (pay back period of initial cost) and energy savings.

The development of the optimized standards is presented with a form which the homeowner can use to determine how much energy he could save by increased insulation, storm windows, etc.

THERMAL LOSS/GAIN CONTROL

Topic: Energy Conservation Study

Source: Smith, D.L., Letter concerning energy conservation research at the University of Cincinnati

Affiliation: University of Cincinnati, Cincinnati, Ohio

Synopsis: In his letter, Dr. Smith discussed the objectives of a recently initiated research project in the area of energy conservation, with primary interest on the potential of solar energy as an alternative energy source. They are attempting to investigate and test several alternative physical design concepts (building construction techniques) and to analyze and evaluate computer modeling techniques.

They plan to build a structure (plans available) and develop the mathematical analysis by the fall of 1975. Solar collector designs and alternative interior surface characteristics will also be studied.

THERMAL LOSS/GAIN CONTROL

Topic: Architectural Features of A Solar Home

(Refer to Page C - 32)

SOLAR ENERGY COLLECTION

Topic: Comparison of Several Solar Collector Configurations

Source: Lior, Noam, and A. J. Saunders, "Solar Collector Performance Studies," Report No. NSF/RANN/SE/G127976/TR73/1 (August, 1974); Personal Interview (June, 1975).

Affiliation: University of Pennsylvania, National Center for Energy Management and Power, Philadelphia, Pennsylvania 19174

Synopsis: This paper incorporates the analytical study and experimental testing of 21 configurations of solar collectors. Simultaneous experiments were performed on two collectors, one being a test specimen, the other, the reference collector, a double glazed flat black collector. Insulation and heat loss tests were performed. Parameters among the various collectors were number of glass plates (glazing), width of air gaps, plate material and thickness, absorber coatings, and convection suppression honeycomb structures of various materials, depths, and cell inclinations. The main comparative testing apparatus was portable and had adjustable inclination and tested 1 ft x 1 ft collector models. An additional facility was used for some models which individually tested 4 ft x 8 ft collectors placed vertically. All collectors had a copper plate absorber with a fused serpentine copper coil on its back side through which the collector fluid passed.

Experimentation concerning spacing between plates, and plate absorber indicated that the optimum gap should be 3/8". Three spacings were tested, 1/4", 3/8", 1/2". The heat loss decreased asymptotically with gap thickness and any size above 3/8" showed insignificant improvement. Also, collector cost increases with increasing spacing.

On an efficiency ratio (with reference collector) basis the best collector designs were, in descending order:

- (1) Single and double glazed, 3/8" space, 1/8" glass, selective black coating (4:1 Visual/Infrared Dark Mirror Coating, OCLI-type 12-5556-72, Optical Lab., Inc., Santa Rosa, Cal). The single-glazed was the best over the ambient temperature range tested but it is felt that the double-glazed would perform better at lower ambient temperatures. The single glazed was 17% better than the reference collector (to be described later) and the double-glazed 11% better.
- (2) Reference collector - double glazed, 3/8" space, 1/8" glaze, flat black coating (Krylon No. 1602 Ultra-Flat Black Enamel), Borden Inc., Columbus, Ohio)
- (3) Single glazed 1/8" glass, 3/8" space, 7/16" honey-combed structure at 60° angle with absorber. Its efficiency was about the same as the reference collector. Others tested had different spacing, various honeycombed features, various glass thickness, and various sized plexiglass

glazing in place of glass. The ones performing nearly as well as the reference were those using plexiglass but this material was found to fatigue after continued usage at the high temperatures.

In a later report* these were compared as a relative cost effectiveness basis again using the reference collector. The most cost effective was the single glazed mentioned in (1) above, 50% better than reference, next was that mentioned in (3) 15% better; third was the double glazed mentioned in (1) 18% better, and fourth was the reference collector, (2) above.

High and low prices figured at the time of this report had the reference collector at from \$5 to \$9.50/sq ft., the single and double glazed in (1) at \$4.40 to \$6.90/sq ft. and \$5.40 to \$9.90/sq ft., respectively and that mentioned in (3) at \$4.70 to \$7.70/sq ft.)**

During a personal interview Dr. Lior discussed his report with these additional comments:

After careful study, Dr. Lior elected to study collectors utilizing a water-antifreeze mixture as the collector fluid as opposed to air. He discussed the advantages of liquid vs. air as follows:

- (1) Liquid needs less collector area to collect the same BTU's.
- (2) Liquid is easier to transport-small pipes vs large ducts.
- (3) Liquid is easier to seal against leakage at the collector
- (4) Liquids allow for direct storage of energy, or if another storage medium is used, less heat exchange area is needed. For air system another storage medium is needed.
- (5) Less power is required to move the liquid.

Disadvantages of liquid vs. air is as follows:

- (1) Water or water/antifreeze is contaminative presenting a leakage problem.
- (2) Energy can be directly transported by the air to the spaces to be heated.
- (3) Air is more available than water.

Dr. Lior recommended a double glazed collector made of available components: Roll-bond aluminum absorber, painted black,*** covered by conventional thermopane (small gap between two panes). He also considered vertical installation (15% less efficient than proper angle for Philadelphia region) to be more viable due to the possibly easier integration into the house wall design, especially for retrofit where improper roof angles are present. (Of course, the further south, the less efficient is the vertical collector).

Dr. Lior also discussed other areas including night time cold storage using a heat pump and some general evaluation at University of Pennsylvania involving energy conservation by means of

storage and solar heating. These are presented in other synopses.

* NSF/RANN/SE/G127976/PR73/5, "Conservation and Better Utilization of Electric Power by Means of Thermal Energy Storage and Solar Heating". National Center for Energy Management and Power.

** Prices based on using roll bond aluminum as absorber.

***The selective black coating mentioned above is preferred.

SOLAR ENERGY COLLECTION

Topic: Analytical Comparison of Collectors

Source: Hsieh, C.K. and S.K. Srivatsa, "Performance of Single and Double Glass Covered Solar Energy Collectors," ASME Publication 74-Wa/Sol-9, (August, 1974)

Affiliation: University of Florida, Dept. of Mechanical Engineering, Gainesville, Florida

Synopsis: This paper presents an analytical discussion of solar collectors, comparing single and double glazed models with various degrees of coating (number of surfaces). The authors include reflection, absorbtance, and transmissivity of each surface including the absorber, also accounting for convection losses and temperature increase of the absorber medium. The model is considered to be flat and horizontal. (The horizontal assumption allows for maximum convection loss) Theoretical curves are generated for both single and double glazed with from none to all but the outside surface coated with MgF_2 . The MgF_2 yields minimum reflectance at normal incidence and lower reflectance at large incidence angles.

The authors use two theoretical locations: Miami and Minneapolis. From their analysis they conclude: (1) For a given flowrate through the collector the outlet temperature in Miami remains approximately constant during the small seasonal ambient temperature variations, while in Minneapolis the change in outlet temperature from winter to summer is about $2^{\circ}C$ for the double-glazed collector. (2) The coatings improve the overall efficiency of the collector. (3) Coatings on outside surfaces may not be weather resistant. (4) Even if the double glazed has coatings on four surfaces it does not match the single glazed system with no coatings for efficiency. (5) At increasing angles from normal incidence, the single glazed performs increasingly better.

SOLAR ENERGY COLLECTION

Topic: Thermal Trap Solar Collector

Source: San Martin, R.L., "Performance of the Thermal Trap Solar Collector," ASME Publication 74-WA/Sol-5 (July, 1974)

Affiliation: New Mexico State University, Dept. of Mechanical Engineering, Las Cruces, New Mexico

Synopsis: The thermal trap solar collector discussed consists of a conventional black absorber surface on which is placed a 4.08cm-thick solid slab of methyl methacrylate which has a high transmittance at short wave lengths (Sun) and a low transmittance at longer wave lengths (absorber) and also a low thermal conductivity. Tests were performed with and without an air gap and glazing on outside. A water-glazed mixture was passed through the absorber and its' inlet and outlet temperatures, collector face temperatures and other pertinent data, (including insolation) recorded.

The collector exhibited high efficiencies up to 70% in January and 75% in March with glazing and surprisingly 88% in March without glazing. Ambient temperature for those days was not listed in the report. Temperatures collected on these dates were 65°C, 71°C, and 77°C, respectively.

The collector favored the afternoon period and appeared to give more useful collector time than one would expect of a conventional collector, being less susceptible to variations in operation due to intermittent cloud cover.

The increase in efficiency when glazing was removed was probably due to extra insolation received outweighing heat loss due to increased convective loss.

This author's thoughts are (1) It would have been helpful to have side by side tests of thermal trap device and conventional single-glazed and no-glazing collectors. (2) Very promising for higher temperature collection for absorption A/C (3) Need cost figures to determine if material is cost effective.

SOLAR ENERGY COLLECTION

Topic: Solar Augmented Heat Pump and Collector Performance
(Refer to Page C - 38)

SOLAR ENERGY COLLECTION

Topic: Optimization of a Solar Assisted Heat Pump System

(Refer to Page C - 40)

SOLAR ENERGY COLLECTION

Topic: Use of Air as a Collector Medium

(Refer to Page C - 34)

SOLAR ENERGY COLLECTION

Topic: A Solar Collector Which Heats Attic Air

(Refer to Page C-36)

SOLAR ENERGY STORAGE

Topic: Sensible and Latent Heat Solar Energy Storage

Source: Telkes, M., "Solar Energy Storage," ASHRAE Journal, pp. 38-44 (September, 1974)

Affiliation: University of Delaware, Institute of Energy Conversion, Newark, Delaware

Synopsis: Dr. Telkes discusses the advantages of using a heat of fusion material for thermal storage. It would occupy one-eighth the volume storage of water, with the added advantage of having a constant temperature which is important for higher heat pump COP's. An investigation of various media was made with cost, latent heat, melting congruency, and melting point temperature being primary criteria. Most experimental work was performed with salt hydrates and their eutectics (waxes were ruled out because of higher cost and their potential as fire hazards).

Dr. Telkes recommends the use of sodium sulfate decahydrate for solar energy storage (melting point - 90°F, heat of fusion - 108 BTU/lb). One problem which exists with this salt is a settling out of sodium sulfate, which may be alleviated by inversion or mixing of the solution, or possibly proper heat exchanger design. Various thickening agents (to prevent settling) have been used. Some perform well for a limited number of freezing/melting cycles.

An eutectic of sodium sulfate decahydrate is being investigated for storage at 55°F also requiring thickening agents. The settling out tends to reduce the latent heat of fusion.

The cost of the above mentioned materials appears to be low but may be compensated for by the increased cost of proper heat exchangers. Heat exchanger experiments are being conducted at the University of Delaware's solar home, Solar I.

During a recent interview with Dr. Warfield, Head of the Institute of Energy Conversion at the University of Delaware, he indicated that they had developed a material which could store energy at 120°F and are in the final stages of a 55°F storage material. Publication of their present work should be forthcoming.

SOLAR ENERGY STORAGE

Topic: Materials for the Storage of Solar Energy

Source: Altman, M., and H. Yeh, "Conservation and Better Utilization of Electric Power by Means of Thermal Energy Storage and Solar Heating", Report No. NSF/RANN/SE/GI27976/PR73/5, (July, 1973); Personal Interview with Dr. Noam Lior (June, 1975).

Affiliation: University of Pennsylvania, National Center for Energy Management and Power, Philadelphia, Pennsylvania.

Synopsis: The results of an investigation of various latent-heat-of-fusion materials as thermal storage media was presented in this report. Selection criteria were developed for the materials prior to testing: proper melting temperature, large heat of fusion, congruent melting, no supercooling, stability, inertness, non-perilousness, and low cost. Types of materials tested were salt-hydrates, sodium sulfate decahydrate and its mixtures, organic compounds and organic eutectics. A systematic survey of salt-hydrates were performed; no previously unknown materials having high heats of fusion, suitable melting points, and low cost were found. Due to incongruent melting, sodium sulfate decahydrate mixtures lose their initial high thermal storage capacity. (After several freeze-thaw cycles of sodium sulfate decahydrate at the 90°F melting point, its latent heat decreases from 108BTU/lb to less than half of this value). This is due to settling out of anhydrous sodium sulfate. More than twenty thickening agents were tried but none prevented this settling out for more than ten cycles.

Two organic waxes show promise for use as storage media. Sunoco P116 (116°F) with a latent heat of 90BTU/lb and Enjay C₁₅ - C₁₆ paraffin (40-50°F) with a heat of fusion of 65BTU/lb. These waxes cost approximately \$.75/1000BTU of storage. Clathrate and semi-clathrate hydrates melting in the desired temperature ranges have heats of fusion in excess of 100BTU/lb and are low in cost. These deserve further development.

SOLAR ENERGY STORAGE

Topic: Use of Paraffins for Thermal Energy Storage

Source: Bailey, J. A., et.al., "A Solar Energy Storage Subsystem Utilizing the Latent Heat of Fusion of Paraffin Hydrocarbons - a Progress Report", North Carolina State University at Raleigh, School of Engineering. (June, 1975)

Affiliation: North Carolina State University, Raleigh, North Carolina

Synopsis: In this paper is discussed an analytical and experimental research program designed to assess the potential of a solar energy storage subsystem utilizing the latent heat of fusion of paraffin hydrocarbons for the heating and cooling of buildings. An idealized model was assumed and analytically studied using various parameters such as inlet and outlet temperature changes, effective thermal conductivities, latent heats, etc. Various curves are generated using the equations developed.

An experimental model is described and a program developed for testing and comparison with theoretical results. No experimental results are as yet available.

No cost analysis was given in this report.

SOLAR ENERGY STORAGE

Topic: Use of Ground Water Aquifiers for Heat Storage

Source: Tilmann, S.E., Letter describing present research

Affiliation: Michigan State University, East Lansing, Michigan

Synopsis: In his letter, Dr. Tilmann discussed research in which he is engaged to develop a uniform procedure for evaluating ground water aquifiers, suitable for heat storage wells. Economic studies indicate that the cost/benefit break point is a heat storage system of this type servicing from 1000-2000 single family dwellings, which with additional research and design may be reduced to 10-20 families.

The wells would be used for storage of solar energy with a possibility of 75% recovery after six months storage. Dr. Tilmann lists several advantages, three being: (1) "cold" storage is also possible, (2) reasonable installation costs, and (3) technology to install a system is readily available.

Systems of this type should be available in five years but application to single family residences is questionable.

SOLAR ENERGY STORAGE

Topic: Storage of Energy Within the Absorption Cycle

Source: Baughn, James, and A. Jackman, "Solar Energy Storage Within the Absorption Cycle," ASME Publication 74-WA/HT-18 (August, 1974)

Affiliation: University of California, Departments of Mechanical and Chemical Engineering, respectively, Davis, California.

Synopsis: Authors discuss the conventional absorption cycle using solar energy in the generator (via liquid). They discuss briefly its use as a heat pump and air conditioner during sunny hours with conventional means of storage for non-sunny days.

The main theme of the paper is an analytical investigation of solar energy storage within the cycle itself. In this system there are three storage areas (1) liquid refrigerant between condensor and evaporation (2) weak solution between generator and absorber (return from generator to absorber) (3) strong solution between absorber and generator. Operation modes may include parts of or all of the system. For example, during inadequate insolation periods, stored refrigerant is vaporized in the evaporator, absorbing heat, then combined with stored weak solution in the absorber (releasing heat) to form a strong solution which is stored. Heating is obtained by passing interior air over the absorber and exterior air over the evaporator, and cooling by passing interior air over the evaporator and exterior air over the absorber. During high insolation strong solution would be generated by operating only the generator and condensor and returning liquid refrigerant and weak solution to storage. One definite advantage is that energy is formed as latent heat requiring less space than conventional rock or water storage. Disadvantages include expensive storage materials, and relatively high pressure storage required for most refrigerant absorbent pairs.

A comparison was made of several refrigerant-absorbent pairs on the basis of storage volume required to pump 10^9 joules (948,600 BTU), about 10 days storage for low consumption home. Water/lithium bromide is attractive because of low storage volume and pressure. Ammonia/water has low storage volume and low cost but high storage pressure. Others were also compared as well as sensible heat storage devices. One advantage over sensible heat storage is it can be stored much longer, needing little or no insulation.

Conclusions were (1) storage within absorption cycle is feasible, (2) it is more expensive than direct solar, short time storage heating, (3) ideal refrigerant/absorbent are not available, but some are promising, and (4) system is highly efficient-- may be possible to deliver twice as much energy to interior air as was collected by solar collector.
(COP=2)

SOLAR ENERGY STORAGE

Topic: Heat Pump Performance Using Various Storage Techniques.

(Refer to Page C - 43)

SOLAR ENERGY STORAGE

Topic: Optimization of a Solar Assisted Heat Pump System

(Refer to Page C - 40)

SOLAR ENERGY UTILIZATION - HEATING

Topic: Solar Energy Recovery Systems - The Solar Home

Source: Mumma, S., (Provided by), "Solar Energy Recovery Systems," A Progress Report, Ohio State University (July, 1975), Personal Interview (July, 1975)

Affiliation: Ohio State University, Dept. of Mechanical Engineering, Columbus, Ohio

Synopsis: This is a progress report on the research being conducted in Ohio State's Solar Home, a 2200ft.² single-story research dwelling utilizing solar energy recovery systems. Data has been collected since March, 1975.

The home utilizes solar collection, using a water-antifreeze mixture which may heat hot water in a heat exchanger, heat interior air in a heat exchanger-duct, heat cold side refrigerant of a heat pump, be used in the generator of an absorption cooling heat or go to storage. These systems are contained within the house, the storage tanks being directly beneath.

From the short term data already taken, they have reported: (1) Savings of 65% for hot water heating and 55% for home heating can be accomplished using solar recovery. (2) Installation or retrofitting with solar recovery system may cost \$7,000 to \$10,000, at today's prices. (3) In most northern areas, back up units will be required. (4) Electric utility service will still be required. (5) No conclusive data is yet available on home cooling using solar energy. (6) University engineers will continue to conduct research at the Solar Home with the aim of increasing cost savings, simplifying the total system, and modifying cooling systems to achieve economy in solar-powered air conditioning.

The cooling system is a solar hot water powered lithium/bromide absorption unit. Various manufacturers have provided solar devices for testing (collectors, etc.). At present, thermal energy storage is in 2-2000 gal. water tanks which after full storage can heat the home up to 4 days.

They utilize two solar heating systems (1) direct hot water to home air and (2) hot water to storage to heat pump to home air. There are 660ft² of solar collectors, heating water up to 190°F (for absorption unit and hot water). Storage may be at lower temperature.

During a personal interview, the Solar Home was visited and discussed more at length. There are only four small windows (1 ft wide by 5 ft high, not openable)

located on the south wall (living and dining space.) A unique feature of the house is the use of four atria located so that every room opens into at least one. The atria, approximately 8 ft by 8 ft, are covered with double panes, having a reflective mirror coating to reflect heat, but allowing light through. The house is insulated by styrofoam on the outside in place of standard fiberglass between studs. The house was occupied for less than one year by a five member family. Instrumentation (except for the thermostat) was located in the 2-car garage area to minimize disturbance of the residents. Approximate cost of the house is \$150,000. As mentioned in the report, the heating system is so designed as to use solar energy directly for home heating, or pass this energy to storage for supply to the heat pump. As yet, the two heating modes of operation are not automatically switchable. They are using a General Electric Heat Pump Unit and data indicates a maximum COP of approximately 3.0 which occurs when the evaporator cooling water outlet temperature is approximately 45°F. This outlet temperature can be maintained by automatic recirculation of the outlet water to mix with the incoming storage water. They have experimented with direct storage of collector medium (water-antifreeze) and also storage of solar energy in distilled water by use of a heat exchanger.

The 660 sq. ft. of collectors are PPG double glazed flat black roll-bond aluminum plates.

As of this date, no conclusive data as to the effectiveness of solar augmentation of the Arkla 3-ton absorption cooling unit. Its cost plus the cost of a cooling tower add to be approximately \$3600. Further work and modification of this system are necessary before any conclusions can be derived as to its cost effectiveness.

It appears that possibly less collector area and storage volume is required for operation in the heat pump mode. Dr. Mumma plans to do experiments with these reduced sizes next winter.

Other projects being undertaken at Ohio State are: (1) The measurement and calculation of the thermal diffusivity of organic phase-change materials (paraffins) for thermal storage and optimization of phase change material containers. Paraffins are promising as thermal storage mediums but need research to find means to increase their thermal diffusivity. (2) Development of heat pump controls in conjunction with G.E. and Penn Controls (Tom Hayes, Penn Controls, Goshen, Indiana)

SOLAR ENERGY UTILIZATION - HEATING

Topic: Solar-Assisted Heat Pump in a Test Residential House

Source: Warfield, G., Director, Institute of Energy Conversion.
Personal Interview (June, 1975).

Affiliation: University of Delaware, Newark, Del., 19711

Synopsis: Discussions with Dr. Warfield concerned the many different projects they are working on mainly directly linked to their test house, Solar I. Dr. Warfield said that 75% of their effort is in developing Cadmium Sulfide Solar Cells which are being produced by a company near the campus. Solar I differs from other solar test facilities in that it converts solar energy to heat and electricity.

The solar collectors contain solar cells whose backs heat to a high temperature of 140°F, where air is passed over and then into a heat storage medium. As mentioned air is the collecting medium, and latent heat-of-fusion materials are used as the storage medium. Some salts have fusion temperatures of 55° for storage of "cold". Dr. Warfield said that the 120° material is ready for use but a little more work needs to be done on the 55° material.

In the winter the air is circulated behind the cells through the collector. It then passes through a heat exchanger yielding heat to melt the heat-of-fusion material or may go directly to house duct system and heat the house directly. After passing through the exchanger (or house), the air is then passed through the collector again. Air flow is enough to maintain approximately 120° temperature in the exchanger (130° to 140° in the collector). During the day heat is delivered to the house heating air (1) directly by mass transfer, receiving air directly from the collector, (2) by heat transfer with the melted storage medium thus "freezing" it while the collector medium tends to heat up, (3) on cloudy days when heat is not collected by the collectors, a heat pump delivers energy to the house heating air. On winter nights, after energy has been stored in the melted salt, the house heating air system collects heat from the salt freezing it and heating the house. The heat pump may be used as above if enough heat has not been stored. At night, air is not passed through the solar collectors.

During summer operation the solar collectors are generally not used for air heating. Although some air may be passed through by chimney action or a fan to

maintain the solar cells at a low enough temperature (160°) to prevent damage to the cell. In the summer, the heat pump acts as an air conditioner, but not conventionally, as it pumps heat from the cold storage fluid, (55°) to the lower temperature night air, freezing the storage medium. Air is passed over this storage medium during the day, giving up heat to it, melting it, and then allowing cool air to be delivered to the house. The night time use of the heat pump has two advantages. (1) Uses electricity at off peak house (lower cost) (2) Uses lower night temperatures increasing COP. A backup reservoir at 75° is also available.

At present, Solar I is using pneumatic (air) controlled dampers and valves to select the modes of operation mentioned above. They are in the process of developing an electronic control system which would reduce cost and maintenance.

The solar collectors are single glazed units with an additional plexiglass cover after integral installation in the roof. Additional vertical window type units are also installed where air is directed behind the windows to pick up additional solar heat through the windows.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Solar-Assisted Heat Pump Using Attic Air

Source: Bourne, R.C., Letter describing the "Solar Heat Pump" home in Lincoln, Nebraska (June, 1975); personal interview (June, 1975)

Affiliation: University of Nebraska, College of Engineering Technology, Lincoln, Nebraska

Synopsis: A 1089 sq. ft. home is under construction in Lincoln, Nebraska which will utilize solar heated attic air to provide interior heat. Its estimated cost is under \$30,000. The house will not use expensive solar collectors but will have its south-facing roof a transparent surface allowing solar energy to heat the attic air. It has two distinct advantages: (1) It replaces conventional roof at the same price, and (2) It utilizes low temperature collection for less radiative and convection losses.

A heat pump can be utilized conventionally (using outside air) when attic temperature is low or may extract heat from the attic air, when attic temperature is high and deliver this heat to a water storage system which when circulated through the water/air heat exchanger delivers heat through the ductwork to the house. The heat pump and storage are sized to store enough heat in twelve hours' operation for 24 hours' heating at outside temperature of 20°F.

For summer use, the system utilizes off-peak operation, the heat pump chilling at night, the water which will be used to cool the interior air. Eight hours operation in the cooling mode will cool the house for 24 hours on the hottest day.

It is estimated that the annual heating and cooling cost will be \$75.

The house will have extra insulation, inside window closures and other energy conservation features and will be fully instrumented. A control system will cycle the heat pump for operation at optimum modes.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Residential Solar Heating and Hot Water Systems

Source: Farber, E. A., et.al., "A Case Study: Utilization of Solar Energy in Residential Dwellings", ASME Publication 74-WA/Sol-2 (July, 1974)

Affiliation: University of Florida, Energy Conversion Laboratory, Gainesville, Florida

Synopsis: In this paper, the authors discuss, generally, the applicability of solar energy to residential space heating and domestic hot water heating, also discussing the availability of solar energy in the U. S.

The paper generally describes the University of Florida's solar research residence which has recently been converted to utilize solar energy. The hot water system uses natural convection to cause flow through the collector and hot water system (a design which is over 15 years old) and the space heating is a hydronic system using hot water from storage to heat the house directly. These systems as well as solar heated forced hot air systems are described.

Emphasized in the paper are the basic parameters to be considered when installing solar collectors - floor space to be heated, wall area, type of insulation, infiltration rate and other heat loss parameters.

Data obtained from the solar residence are not yet complete due to various modifications during the past two years but preliminary data indicate that space heating and domestic hot water can be furnished reliably with solar energy.

In discussions with Dr. H.A. Ingley at the University of Florida, he indicated that the results of a study conducted at the University Solar residence concerning space heating would be available in January 1976. The study concerns itself with the direct use of solar energy for heating, using hot water baseboard convectors of forced air. Analytical and experimental test results will be presented.

Work is also being done in the areas of solar cooking, solar distillation, solar collection, and residential size solar powered electrical generation. A report on the electrical system should be available about January 1976.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Solar Augmented Heat Pump and Collector Performance

Source: Converse, A. O., "The Assessment of Solar Heated Buildings and Panels", Quarterly Progress Report #1 (March, 1975).

Affiliation: Dartmouth College, Hanover, New Hampshire.

Synopsis: This report discusses the performance of the deVries solar heated building in White River Junction, Vermont during the period of December 20, 1974 through March 13, 1975. The building has 2000 sq. ft. of area, utilizing three York DW 30H heat pump units, 910 sq. ft. of collector (720 sq. ft. now in use), and a 3600 gallon storage tank installed in the ground under the floor slab. The collectors are made by Sol-R-Tech and contain two sheets of "Kalwall" (fiberglass reinforced polyester sheet) over aluminum "Rollbond" painted flat black and are situated on the roof facing south at an angle of 45°. A schematic of the system was not included. The report did include a description of instrumentation.

During the testing period heat pump COP's were found to range from 2.1 at 62°F storage temperature to 2.99 at 83°F storage temperature. (Published York values range from 3.41 to 3.90 at these temperatures but they are steady state values and do not include start-up transients).

The collector panels (\$6.00/sq.ft.) appeared to be as good or better than other commercial panels, and obtained average daily efficiencies of 36% to 41%, with short term efficiencies ranging from 40% to 65% depending on ambient temperature.

The system as a whole provided approximately 30% of the total energy requirement of the house (lighting not included) during the testing period.

The report also discusses pitting corrosion in aluminum solar absorber material. Chromate inhibition (500 ppm) is presently being practiced in the collector medium (water).

Work will continue in the areas of corrosion, heat pump use as an air conditioner in summer using the collectors as night time radiators, heat pump steady state performance, and collector performance.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Modeling of Solar Heating and Air Conditioning

Source: Duffie, J. A., and W. A. Beckman, "Modeling of Solar Heating and Air Conditioning," Semi-annual Progress Report-NSF/RANN/SE/GI34029/PR/74/2 (October, 1974).

Affiliation: University of Wisconsin-Madison, Solar Energy Laboratory, Madison, Wisconsin.

Synopsis: This progress report describes refinements of the general solar process simulation program, TRNSYS, and refinements and reformulation of several of the component models and addition of new component models to the TRNSYS Library. TRNSYS, a FORTRAN computer program for simulating the dynamic thermal behavior of transient systems, is a general program for solving sets of differential and algebraic equations which describe solar energy systems based on a modular approach.

Work on heat pump system models is underway and preliminary simulations suggest the operation of solar space heating systems can be significantly enhanced when a heat pump is placed between the collector and load. More work will be done to expand the usefulness of routines recently developed.

Progress is being made on modeling of rock-bed storage systems, as well as phase-change energy storage. A computer program has been written which simulates the transient operation of the Rankine cycle. The Arkla 3-ton absorption air conditioner has been modeled but needs refinement.

Included in the report are (1) paper describing the versatility of TRNSYS, comparing similar but slightly different systems; (2) paper describing calculation of loss coefficients for flat plate collectors of various parameters, and (3) a modeling of the Colorado State University solar house heating and cooling system.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Optimization of a Solar Assisted Heat Pump System

Source: Moore, B. W., "An Evaluation of a Heat Pump Solar Energy System for Home Heating", Thesis (February, 1975); Personal Interview with Dr. Leon Glicksman, Thesis Supervisor (July, 1975).

Affiliation: Massachusetts Institute of Technology, Cambridge, Massachusetts.

Synopsis: In this thesis is presented a very detailed discussion of each of several facets which must be considered in optimization of a heat pump, solar collector, and heat storage system. A detailed analysis of the collector, storage system and heat pump is presented, including performance equations either developed or obtained from appropriate literature. Basic assumptions are amplified in order that the model fit the solar system. The optimized systems were those which, by proper combinations of collectors, storage systems, and heat pumps produced the maximum cost savings to the consumer, including initial and operating costs with present day interest rates included (pay back in 15 years and 25 years). Parameters included solar collector area and amounts of glazing, storage tank capacity, and various heat pump models using manufacturers performance data. Optimization studies were for particular application in the Boston area and Minneapolis area, using appropriate weather data. One important conclusion found was that for Boston, Minneapolis, and areas of similar climate, double-glazed flat black collectors appear to be more cost-effective than single glazed. Some general system costs are also presented.

Appendices included discussion of solar radiation, properties, heat pump performance curve fitting and the computer program used in the optimization.

In an interview with Dr. Glicksman he said that work was continuing at MIT on optimization techniques for collector, storage and heat pump combinations.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Heating and Cooling Systems Comparison - Including Solar

Source: Calvert, F.O. and D.G. Harden, "Hybrid Solar Energy and Electric Heat Pump," ASME Publication 73-WA/Sol5 (August, 1973)

Affiliation: University of Oklahoma, Depts. of Architecture and Mechanical Engineering, respectively, Norman, Oklahoma

Synopsis: The authors compare the yearly energy usage of various systems for a 1500ft² residential home, ranging from all electric (with electric heat pump for heating and cooling) to primarily gas (with gas furnace and gas absorption cooling) and combinations of the above. The comparison is analytical utilizing actual weather data for the home location (Oklahoma). A basis for comparison is a concept called the "Energy Utilization Factor" defined as

$$\text{E.U.F.} = \frac{\text{Desired energy transfer}}{\text{Fuel input from basic resource for the form of energy purchased or produced.}}$$

The best system was based on MCF (thousand cubic feet/year) of natural gas with no emphasis on utility rates, being primarily concerned with energy conservation. The best system was one utilizing a gas furnace, electric A/C, gas water heating, electric cooking and gas clothes drying. The second best was as all electric house (with electric heat pump for heating and cooling) (All heating and cooling systems used forced hot air)

It was also found for heating, the E.U.F. of the heat pump was 0.77 compared to .69 for the gas furnace and for cooling was .62 compared to .34 for gas absorption cooling.

By augmenting the heat pump with heat from solar collectors on the cold side the performance of the heat pump can be improved while the gas furnace is already at or near maximum. In conventional heat pumps with strip heater in the source, during winter months in Oklahoma, 1/3 of the energy used by the heat pump is in these resistance heaters. Solar heating could alleviate this cost.

Since the best operating temperature for heat pump sources is approximately 50°F, solar energy could be taken and stored at lower temperature than if the solar energy area used directly. This yields higher collector efficiency and lower storage losses. Calculations showed solar energy yielded 62% of the January heating requirement. (Without storage 6% was saved) Paper made no mention of solar aid to cooling.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Heat Pump Performance

Source: Balasubramaniam, M., et. al. "Solar Thermal Absorption Heat Pump Breakeven Coefficient of Performance," ASME Publication 74-WA/Ener-2 (Sept., 1974)

Affiliation: University of Pennsylvania, National Center for Energy Management and Power, Philadelphia, Pa.

Synopsis: This paper compares two modes of heating using solar energy: (1) Direct solar heating using the collector medium directly to heat, and (2) Solar absorption heat pump where the solar collector medium is used as the heat source in the generator of an absorption type heat pump. In the latter, heat is additionally received through the evaporator from the outside air and discharged to the heated space through the absorber and condenser.

It is shown analytically that in order to deliver the same temperature medium to the heated space, the temperature of the collector medium of the heat pump must be higher than that of the direct solar heater. Experimental data shows a drastic decrease in collector overall efficiency with increases in temperature. This factor leads to the conclusion that with present solar collector efficiencies and ideal heat pump COP's, for collector temperatures above 125°F, more heat can be delivered directly than by absorption heat pumps for the same collector area.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Heat Pump Performance Using Various Storage Techniques

Source: Lawrence, R.A., "Performance of Heat Pumps Using Cold Side Energy Storage and Unconventional Heat Sources," ASME Publication 74-WA/HT-17 (August, 1974)

Affiliation: Ohio University, Dept. of Mechanical Engineering, Athens, Ohio

Synopsis: This paper is a parametric comparison of various techniques for reducing operating costs of heat pumps in colder climates of the U.S., utilizing several storage techniques including solar energy collection and storage. Other techniques include increasing heat pump cold side temperatures by (1) storing, in a conventional storage system, heat from outside air on warm winter days, (2) using existing pools where temperature (due to solar radiation) is higher than atmosphere, and (3) utilizing underground wells for cold side storage.

He defines various comparison parameters based on a nominal load day (outside temperature of 7.2°C). He concludes, of course, that storing outside air is insufficient and use of underground water, where available, offers greatest potential for cost savings.

He states that solar collection is not feasible for complete heating since the heat pump, having nominal compressor size, will always require some resistance heating to meet the demand during coldest days no matter how much energy has been collected or stored. This, of course, can be alleviated by using solar energy directly.

SOLAR ENERGY UTILIZATION - HEATING

Topic: Effect of Heat Loss on Solar Heating Systems

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SOLAR ENERGY UTILIZATION - COOLING

Topic: Solar Powered Absorption Air Conditioning

Source: Farber, E.A., et al., "Selection and Evaluation of the University of Florida's Solar Powered Absorption Air Conditioning System", ASME Publication 74-WA/Sol-6 (August 1974); Personal interview with Dr. H.A. Ingley, (August 1975).

Affiliation: University of Florida, Gainesville, Florida

Synopsis: This paper reviews several refrigeration/air conditioning concepts which could utilize the relatively low collection temperatures (less than 200°F) realized by flat-plate solar collectors with water or a water mixture as a collection medium. The advantages and disadvantages of vapor jet, rankine cycle, evaporative and absorption cooling are discussed.

The solar powered absorption system being the most promising, various refrigerant-absorbent combinations are reviewed. Of the combinations reviewed, lithium bromide/water and ammonia/water hold the most promise for solar application, and using available data and computer analysis, several plots were made using such parameters as generator heat input, hot water supply temperature, COP, and condensing water temperature. (A complete analysis of both systems can be found in "Formulation of a Data Base for the Analysis, Evaluation, and Selection of a Low Temperature Solar Powered Air Conditioning System", Final Report NSG Grant GI-39323.) The ammonia/water system was chosen for the University of Florida research residence. (Lithium bromide/water systems have crystallization problems when low temperature heat sources are used.) It is an intermittent system, operating in two cycles: (1) Generation-condensation cycle, during which a charge of refrigerant is generated and stored in the evaporator/condenser (about 45 min.), and (2) Evaporation-absorption cycle, during which thermostatically controlled chilled water is produced. The chilled water may supply from 3 to 6 hours of air-conditioning between charging cycles. In order to provide cooling during cloudy conditions, the system could be oversized and chilled water stored. The system requires complex controls. Preliminary calculations suggest that approximately 18 watts of cooling could be realized per watt of electrical input (pump energy).

In a personal interview, Dr. H.A. Ingley indicated that analytical and experimental test results on the intermittent absorption cooling system would be forthcoming in September 1975, as well as a separate report on a continuous ammonia/water system.

SOLAR ENERGY UTILIZATION - COOLING

Topic: Absorption Air Conditioning

Source: Ward, D.S. and Lof, G.O.G., "Design and Construction of a Residential Solar Heating and Cooling System," Solar Energy, 17, No. 1, 13-20 (April 1975);
Personal Interview (June, 1975))

Affiliation: Colorado State University, Solar Energy
Application Laboratory, Fort Collins, Colorado
80523

Synopsis: It was of interest to explore the efficacy of an operating solar powered absorption cooling unit in a residential building. A 3-ton lithium bromide Arkla-Servel Model 501 cooling unit has been installed in modified form to allow the generator to be driven by hot water instead of a natural gas flame. Full capacity is achieved with hot water supply at 87°C (188°F). Cooling capacity is delivered via forced air flow over the evaporator coils. Apparently the Arkla-Servel 3-ton units are commercially available in modified form for use in solar systems on a limited production basis. The cost of the basic equipment is in the neighborhood of \$2500. In order to improve annual system performance, hence life-cycle cost benefits, the people at Colorado State are suggesting that chilled water storage be incorporated in system design, a concept not included in their original construction.

SOLAR ENERGY UTILIZATION - COOLING

Topic: Absorption Refrigeration Unit Performance

Source: Swartman, R.K., et. al., "Comparison of Ammonia-Water and Ammonia-Sodium Thiocyanate as the Refrigeration-Absorbent in a Solar Refrigeration System," Solar Energy 17, No. 2, 123-127 (May 1975).

Affiliation: The University of Western Ontario, London, Ontario

Synopsis: In this work, Professor Swartman reports on the experimental performance of intermittent absorption chilling while employing ($\text{NH}_3 + \text{H}_2\text{O}$) and ($\text{NH}_3 + \text{Na SCN}$) as refrigerants. For the latter system COP values are reported to range from 0.11 to 0.27 where a flat-plate solar collector and generator for the absorption machine are one and the same unit. Advantages are claimed for the latter system. Quoting from the reference "Conclusions," "In addition to better performance, consideration of the construction costs favors the ammonia-sodium thiocyanate system. Because of the low volatility of the sodium thiocyanate, a rectifying column is not needed in a unit using this absorber, ...". No detailed cost information was given.

SOLAR ENERGY UTILIZATION-COOLING

Topic: Solar Absorption System Optimization

Source: Allen, R.W., et. al., "Optimization Study of Solar Absorption Air Conditioning Systems," Progress Report No. NSF/RANN/SE/GI-39117/PR/74/1 (May 1974) Telephone Conversation (July, 1975)

Affiliation: University of Maryland, Department of Mechanical Engineering, College Park, Maryland

Synopsis: From the abstract "The overall project objective is to study the effect of system options and actual process factors on the performance and optimization of a solar powered absorption air-conditioning system, including the collector and storage. Thermodynamic analysis of the basic and the modified absorption cycle incorporating a liquid-liquid heat exchanger has been completed for the commercial absorption air-conditioning pairs lithium bromide-water and ammonia-water. Characteristic curves of COP versus generator temperature were obtained for prescribed condenser and absorber temperatures (80°F , 100°F , and 120°F) and prescribed evaporator temperatures (40°F , 45°F , and 50°F). Cycle operation was limited by a minimum and a maximum generator temperature. Within this generating range, the maximum COP was below unity, ranging from 0.3 to 0.8. The irreversibility of the absorption cycle was evaluated by comparing the absorption cycle COP with a Carnot cycle COP. The minimum irreversibility occurred at a generator temperature slightly above the minimum required to actuate the cycle. A numerical flat-plate collector model was formulated, based on an existing heat transfer program, and verified for a simple collector configuration. A computer solution to the non-linear differential equation governing the response of the thermal heliotrope was programmed and is currently being made operational."

In a recent telephone conversation, Dr. Allen indicated that further optimization studies had been made and another report is due in the near future. He mentioned that no experimental work was being done at Maryland but that in future work they will be using data from solar powered absorption units in service at other solar houses to compare with their analytical work.

SOLAR ENERGY UTILIZATION - COOLING

Topic: Energy Storage Within The Absorption Cooling Cycle
(Refer to Page C - 28)

SOLAR ENERGY UTILIZATION -- COOLING

Topic: Modeling of Solar Heating and Air Conditioning

(Refer to Page C - 39)

SOLAR ENERGY UTILIZATION - COOLING

Topic: Absorption Cooling in a Solar House

(Refer to Page C - 32)

SOLAR ENERGY UTILIZATION - COOLING

Topic: Proposed Use of Collectors As Night Radiators

(Refer to Page C - 38)

SOLAR ENERGY UTILIZATION - DOMESTIC WATER HEATING

Topic: Solar Energy Heating of Domestic Hot Water

Source: Bowley, W.W. and T.P. Mastronade, "Solar Energy Augmentation for Domestic Hot Water Systems," (A proposed study), University of Connecticut, School of Engineering (April, 1975)

Affiliation: University of Connecticut, School of Engineering, Storrs, Connecticut.

Synopsis: This paper presents a proposed study to be undertaken by the University of Connecticut. The study will involve the placement of a solar hot water heating system in an existing residence to supplement a conventional hot water heater. The paper discusses various systems that have been applied and the selection of a system in which the collectors can be drained when not in use, thus eliminating freezing damage to the collectors. The system will be capable of being retrofitted to existing residential systems without disturbing their conventional operation. The solar system which will preheat the utility supplied water directly using an additional solar energy storage tank is described with associated heat balance equations presented.

A computer model will be developed to allow optimization studies while performance of the system is monitored for a one-year period, the performance characteristics being utilized to improve the computer model. Variables to be optimized are collector area, storage volume and collector tilt angle and orientation. The effect of fluctuating demand patterns will be studied also.

No results of the study are yet available.

SOLAR ENERGY UTILIZATION - PHOTOVOLTAICS

Topic: Solar Energy Conversion to Electricity in a Residential House

Source: Warfield, G., Director, Institute of Energy Conversion. Personal Interview (June, 1975).

Affiliation: University of Delaware, Newark, Del., 19711

Synopsis: Discussions with Dr. Warfield concerned the many different projects they are working on mainly directly linked to their test house, Solar I. Dr. Warfield said that 75% of their effort is in developing Cadmium Sulfide Solar Cells which are being produced by a company near the campus. Solar I differs from other solar test facilities in that it converts energy to heat and electricity.

To obtain electricity, the solar cells are installed on the back surface of the conventional solar collector, a single-glazed collector covered with an additional sheet of plexiglass when installed on the south facing roof. Thus the solar cells utilize the direct radiation to produce D.C. current, while air is passed over the back of the collector (cells) to extract heat at a temperature of approximately 140°F delivering it to storage.

Only a fraction of the collectors installed incorporate solar cells but eventually cells will be installed in all collectors. Presently, these cells provide electricity to appliances and storage cells (golf cart batteries). Present investigations include the use of generated D.C. current directly to appliances, inversion to A.C. current, and methods of tying in with the utility company. The University of Delaware appears to be pioneers in the design and application of Cadmium Sulfide Solar Cells.

A primary concern is development of better methods of D.C. storage. Batteries require space and maintenance.

SOLAR ENERGY UTILIZATION - PHOTOVOLTAICS

Topic: Photovoltaic/Fuel Cells

Source: Backus, C. E., "A Solar-Electric Residential Power System", 7th Intersociety Energy Conversion Engineering Conference, 1972, Paper No. 729110; Personal Interview (June, 1975)

Affiliation: Arizona State University, College of Engineering Sciences, Tempe, Arizona 85281

Synopsis:

Dr. Backus displayed the present technical feasibility of a system utilizing roof-mounted solar cells (silicon) coupled with electrolysis of water and an oxy-hydrogen fuel cell for storage. Assuming data based on residential energy use in the Phoenix, Arizona area he shows that essentially all of the electric load can be met with a net over-production of hydrogen of some 700 pounds per year (returned to the utility.) For system analysis it was assumed that 10,000 KWhr per year were required with a peak in late summer and an expected peak power demand of 20 KW. Although current technology exists for subsystem components, practical economic considerations eliminate immediate application of this residential system until the cost for terrestrial application of solar cells can be reduced by a factor of approximately 1000.

SOLAR ENERGY UTILIZATION - PHOTOVOLTAICS

Topic: Solar Powered Residential Electrical System

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SOLAR ENERGY UTILIZATION - DEHUMIDIFICATION

Topic: Solar Dehumidifier For Large Office Building

Source: Glicksman, L., Abstract "Solar Energy Dehumidification Experiment on the Citicorp Center Building"; Personal Interview (July, 1975).

Affiliation: Massachusetts Institute of Technology, Energy Laboratory, Cambridge, Massachusetts, 02139

Synopsis: This abstract concerns a solar operated dehumidification system for the Citicorp Center Building in New York City. Twenty thousand square feet of collector atop the building (45° facing south) will be utilized to dry chemical-desiccant dehumidifiers, which will absorb moisture from the building cooling air at or near ambient temperatures. This would alleviate the cost of conventional dehumidification where electrical energy is needed to reduce cooling air temperature to below dew point to remove moisture and sometimes reheat before using. Side by side comparisons will be made with the conventional system.

The design, erection, experimentation and data evaluation will be complete in 4 years funded in part by NSF (RANN). Excess solar energy will be used for hot water heating. The system may be retrofitted to existing buildings. Cost of the system is approximately \$900,000 with annual savings of \$47,000 (19 year pay back). Also involved in the project is Con-Edison, MIT, Citicorp, and Loring-Meckler Associates, Inc., consultants.

In a personal interview, Dr. Glicksman said that the conventional system has been modified to eliminate the reheating, thus making the system more cost-effective at the expense of some additional control. This would reduce the annual savings of the solar dehumidification system. Further cost reducing features are being investigated in the solar system.

The concept of solar dehumidification for residential use was discussed. Units this small are unavailable and would be prohibitively costly, but further research should be done concerning the use of solar energy for residential dehumidification, possibly using dry desiccants.

OFF PEAK COOLING

Topic: Two Off-Peak Cooling Systems.

Source: Altman, M., and H.Yeh, "Conservation and Better Utilization of Electric Power by Means of Thermal Energy Storage and Solar Heating", Report No. NSF/RANN/SE/G127976/PR73/5 (July, 1973); Personal Interview with Dr. Noam Lior (June, 1975).

Affiliation: University of Pennsylvania, National Center for Energy Management and Power, Philadelphia, Pennsylvania.

Synopsis: In a section of this report are described several types of off-peak air conditioning systems of which were built and tested prototypes of two of the most promising systems. Both systems used half-sized compressors and evaporators which operate continuously. One system used water as storage medium and employed recondensation of the refrigerant, the refrigerant being condensed by the storage medium after initial evaporation and then reevaporated at a lower temperature for dehumidification. Both evaporators cooled air to be delivered to the house interior. During times when cooling of the house was not required the system operated in a different mode, cooling the storage medium. The system performed well and reduced the peak power requirement by 50% and the total energy use by 6% compared to conventional systems. It was shown that the initial cost of a 4-ton unit of this type was almost 90% (\$1223) greater than a conventional system.

The other system employed a heat of fusion material (salt hydrate) as the thermal storage medium. The conditioned air was pre-cooled by passing through the storage medium (thawing out) and dehumidified and fully cooled in a conventional evaporator. The storage medium is then refrozen by conventionally cooled air during off-demand hours. The peak power demands were reduced by 49% to 0% by the second system, with energy consumption being 10% greater than for conventional systems. The heat of fusion material experienced a loss of available latent heat during continuous cycling.

Since the second system does not offer any energy savings and inconsistent peak power reduction it is not recommended. It is questionable as to the cost-effectiveness of the recondenser system. With only a 6% reduction in energy usage the pay back period for initial cost is long. However, it does reduce peak power demand, and possibly larger systems could realize greater savings.

OFF-PEAK COOLING

Topic: Use of Heat Pump for Off-Peak Cooling

(Refer to Pages C - 34, C - 36)

Topic: Development of A Heat Pump Variable Capacity Control

Source: Glicksman, L. and C. Hiller (Mr. Hiller is a Ph.D candidate under Dr. Glicksman's supervision), Abstract "Variable Cycle Heat Pump Project", (August, 1974) Personal Interview (July, 1975).

Affiliation: Massachusetts Institute of Technology, Energy Laboratory, Cambridge, Massachusetts.

Synopsis: The report discusses the importance of variable capacity in a heat pump system, and addresses itself to the various methods available to achieve this with the advantages and disadvantages of each. A drawback of conventional air-to-air heat pumps is their less than optimum off-design performance. Simply, when the outdoor temperature rises, the mass flow rate of the refrigerant increases caused by density changes with the refrigerant temperature. This effect severely limits the COP and causes the unit to have extreme excess capacity at high ambient temperatures. This is also the effect which causes inadequate capacity at lower than design ambient temperatures, and hence, the requirement for auxiliary (electrical resistance) heating.

The variable capacity heat pump alleviates the first problem by reducing the mass rate increasingly as the ambient temperature increases. The second problem (low ambient temperatures) can then be alleviated by selecting heat pumps with lower temperature design points without fear of losing good COP's at higher temperatures. This, means a higher initial cost but the paper shows analytically that this is overcome by energy savings due to better COP's and reduced auxiliary heating.

The different methods of control are listed below:

- (1) Variable speed-continuous and step
- (2) Cylinder unloading
- (3) Variable clearance volume
- (4) Change of effective displacement via intake valve cut-off control

Method number four (4) is that on which work is being done at M.I.T. Basically, it entails shutting the intake valve off early to reduce the mass rate. The intake valve is actuated by a control which receives its signal from the outside conditions (and possibly superheat conditions). It has the advantages of (1) Being completely variable with 100% to 0% capacity control, (2) Easy adaption to existing designs and units already in service (the only modification, to the compressor in the intake valve) and (3) lower internal losses.

The device is being tested experimentally and is still in the developmental stage. Its estimated cost would be \$20/cylinder.

SYSTEM CONTROL

Topic: System Mode Control

(Refer to Page C - 34)

SYSTEM CONTROL

Topic: Solid State Zone Control

(Refer to Page C - 3)

SYSTEM CONTROLS

Topic: Heat Pump Controls

(Refer to Page C - 32)

APPENDIX D

APPENDIX D

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